Status of JRA1

T. Haas*

January 15, 2007

Abstract

This document summarizes the status of JRA1

*DESY, Hamburg, Germany

1 Introduction

The goal of this JRA is to provide a test beam with a large bore high field magnet and a high precision, fast beam telescope by upgrading an existing facility in Europe. Beam tests of future detectors in a magnetic field are crucial to determine the characteristics of these devices in a realistic environment. In addition an optimal determination of the spatial resolution of the device under test is among the most important tasks in this context. Currently no facility with quick and easy access for the different European groups developing these detectors exists. Facilities at DESY and at CERN have been used so far. DESY provides electron beams up to 6 GeV. CERN has beams with electrons up to 100 GeV and hadrons up to 180 GeV. Groups that presently use these beams have to bring their own dedicated testing equipment. This greatly increases the effort and the time required to do these measurements and it makes the results difficult to compare between groups and competing technologies. In addition the usefulness has been limited due to the lack of a sufficiently strong magnetic field, and by the limitations of existing beam telescopes. The DESY test beam facility has already been intensively used for the test and development of different detector components for the ILC. At the moment three multi-purpose beam areas are available for work at DESY. One of them has been set aside and is being specially equipped for ILC related work. The ongoing upgrade of the DESY test beam facility will hence enable participating institutes to perform necessary tests of their detector developments. After the completion and commissioning, an initial round of experiments is foreseen at the DESY test beam within the four years duration of this proposal. However, the proposed infrastructure upgrade is movable so that it can later be used at other laboratories like CERN. This JRA consists of the following parts:

Magnet Integration of a large bore high field magnet into the existing test beam line.

Environmental Support Improvement of the mounting and cooling infrastructure so that a wide range of different devices can be quickly installed and easily operated.

Pixel Telescope Development and construction of an ultra high precision beam telescope that allows to fully evaluate the precision properties of new devices. One of the candidate pixel technologies for the ILC vertex detector is being used in this device.

Data Acquisition and Evaluation Software Development of a general purpose read out system that can be quickly adapted to individual devices under test and that provides fast concurrent readout of the beam telescope and the device under study.

Validation of Infrastructure The full test beam infrastructure will be evaluated by collaborating with research teams developing competing pixel detector technologies to test their devices in the newly developed infrastructure.

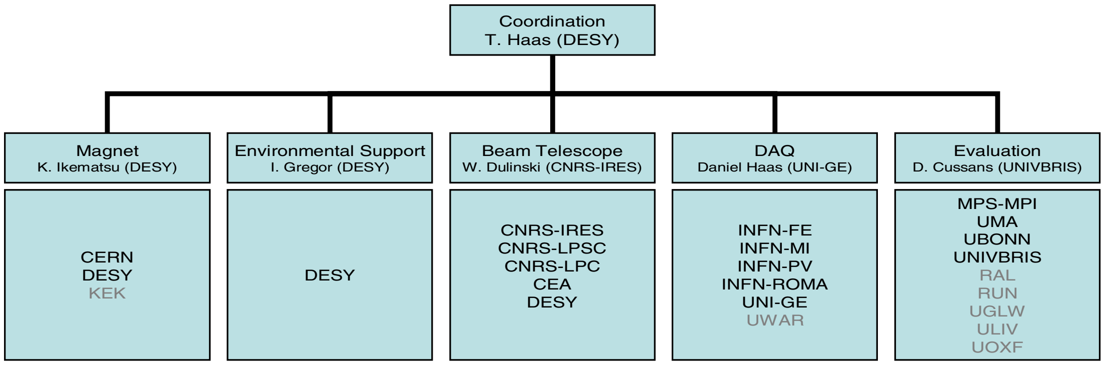

Figure 1: Organisational structure of JRA1. The acronyms given in the lower boxes stand for the participating institutes. They are explained in the appendix.

2 Organization

Fig.1 illustrates the organizational structure of JRA1. The activity is split up into five tasks. The task leaders for the individual tasks have been nominated and the nominations have been approved by the SC. The names of the task leaders with their institutions are given in Fig. 1.

3 Status of the subtasks

As described above JRA1 is divided into 5 tasks. Table 1 lists the milestones of JRA1 as defined in Annex I ("Description of Work") of the contract of EUDET. In this section we review the status of the individual tasks within JRA1 with respect to the milestones and describe the work done in some more detail.

3.1 A: Magnet

A superconducting magnet originally constructed as a spare for a balloon experiment [1] could be obtained on loan from the KEK Laboratory in Tsukuba, Japan. The following properties make this magnet particularly suitable for test beam measurements at the 6 Gev/c electron test beam at the DESY-II synchrotron:

- large bore of diameter 80 cm,

Milestone	Description	Date	Task	Status
JRA1-1	SDC Prototype 1 ready	9	C	completed
JRA1-2	Magnet available	12	A	completed
JRA1-3	SDC Prototype 2 ready	18	C	
JRA1-4	Field map available	18	A	
JRA1-5	Analog Telescope integration in beam	18	B	
JRA1-6	Readout for prototype available	18	D	
JRA1-7	IDC prototype ready	27	C	
JRA1-8	Final pixel telescope integrated in beam	36	B	
JRA1-9	TC ready	36	C	
JRA1-10	Final readout ready	36	D	
JRA1-11	Tracking software available	36	D	
JRA1-12	Test report analog telescope available	36	E	
JRA1-13	Final project reports	48	A,B,C,D,E	

Table 1: List of milestones within JRA1

- very thin cryostat with only $0.2X_0$,
- operation independent of fixed cryogenic infrastructure,
- high magnetic field of up to $B = 1.2$ T.

Early in the first year of the project the details of the lending agreement between KEK and DESY, one of the partners, were finalized as follows:

- The magnet will be lent to DESY for a period of 4 years free of charge,
- The cost for the transport of the magnet to and from DESY as well as the cost of commissioning will be covered out of the EUDET project budget.

The magnet had been in storage at KEK for a while. Therefore it required extensive recommissioning including the acquisition of a number of peripheral components such as power supplies and controls. This work was completed by engineers and technicians at KEK during the summer and fall of 2006. Subsequently the complete system was shipped to DESY where it arrived on 30 November for the final commissioning. This was performed immediately following the arrival of the magnet with the help of a crew of three experts from KEK. Due to the careful preparation of this activity on both sides it was possible to complete it within 10 days and on Monday, 10 December at 15:00 the magnet reached its nominal field value at a current of $I = 437\ A$.
Before this rampup was performed, however, a preliminary security concept was prepared and discussed with the DESY security officers. For the commissioning phase the major concern was the magnet's stray field in publicly accessible areas. According to calculations, it exceeds the acceptable limits for persons wearing artifical pacemakers of 0.7 mT close to the experimental aera where the magnet is located. The stray field does not exceed the limit for the general public of 41 mT in any area that is publicly

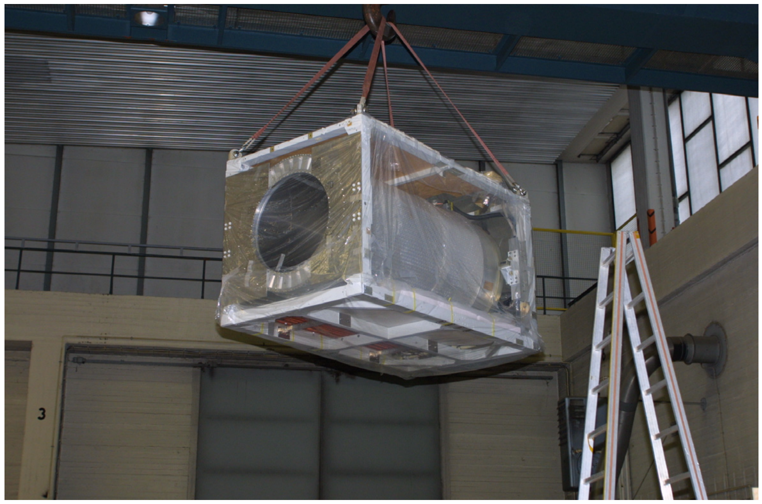

Figure 2: PCMAG is being delivered at DESY

accessible. These calculations were verified by two independent measurements first at 10% of the nominal magnet current and finally at the full magnet current. The measurements agree within 10-15% with the calculations. The calculations and the results of the measurements are documented in Fig. 3 and Tab. 2.

Measurement	$I_{Mag} = 43$ A	$I_{Mag} = 430$ A
1	0.07 mT	0.5 mT
2	0.3 mT	1.0 mT
3	0.4 mT	3.1 mT
4	0.2 mT	0.9 mT
5	0.8 mT	
6	0.1 mT	
7	1.4 mT	12 mT
8	0.3 mT	2.7 mT
9	0.07 mT	0.6 mT
10	0.1 mT	0.4 mT
11	0.2 mT	1.3 mT

Table 2: List of measurements of the stray field of PCMAG at different locations around the experimental area as indicated on Fig. 3

3.2 B: Environmental Support

In the process of designating Beam lines 24 and 24/1 in hall II at DESY for the use of JRA1 the experimental area 24/1 has been renovated and prepared for accepting the magnet PCMAG. Fig. 4 shows a photograph of the renovated This renovation also included laying of gas and power lines.

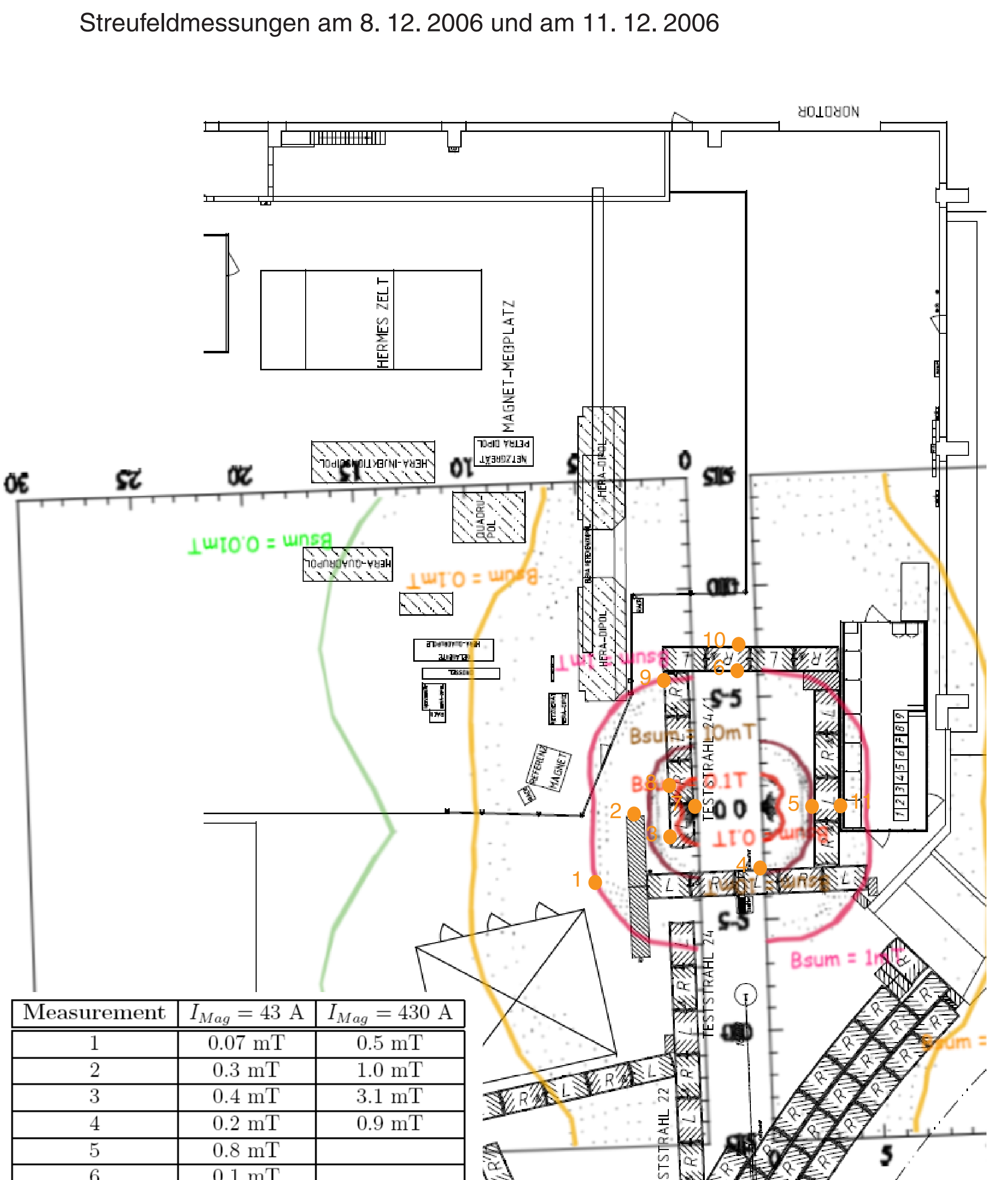

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Figure 3: Layout of hall II at DESY with strayfield measurements. The numbered orange dots correspond to the respective values in the table.

Figure 4: View into the renovated experimental area in hall II at DESY at the beamline 24/1

In parallel, the design of the mechanics and cooling for the pixel telescope has been progressing. The specifications of the overall layout and of the required precision have been finalized. These specifications have been obtained from a simulation of different design options and using different test beam parameters. It is a particular challenge to obtain the desired precision for the extrapolated impact point on the DUT plane in the DESY test beam environment which is strongly affected by multiple scattering due to the low energy of the beam. An exemplary simulation result is shown in Fig 5. From these simulations it was learned that the general setup of the telescope should satisfy these criteria:

- One high resolution reference plane as close as possible to the DUT is needed;
- The optimal choice for the geometrical configuration of the reference planes depends on parameters of the beam and of the DUT. Hence a flexible setup is required;
- The environmental requirements of the reference planes and of the DUT may be quite different. Hence these should be well separated from each other.

The chosen layout follows these criteria and consists of two thermally insulated sensor boxes in which well controlled environmental conditions can be maintained. It is schematically depicted in Fig. 6. The sensor boxes are independent units that can also be operated on their own. The mechanical design of one of the sensor boxes is shown in Fig. 7.

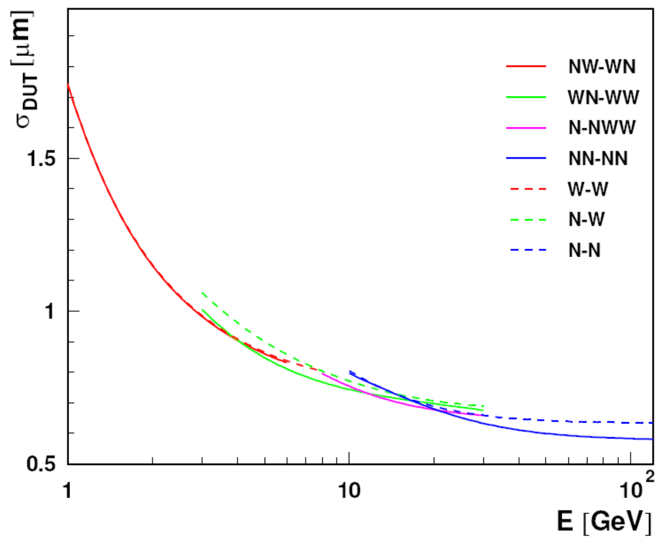

Figure 5: Expected resolution on the DUT plane for the pixel telescope from the simulation. The different lines correspond to slightly different geometrical arrangements of the reference planes with respect to each other.

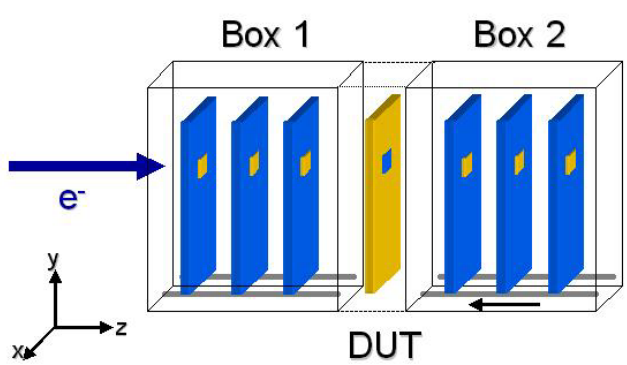

Figure 6: Schematic of the layout foreseen for the pixel telescope.

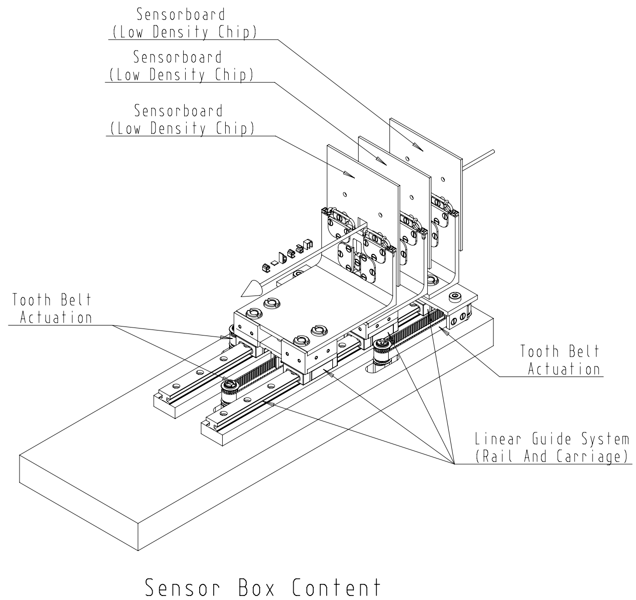

Figure 7: Mechanical design of the interior of one sensor box.

In between the sensor boxes a device under test (DUT) can be placed. A mechanical actuator with two linear and one rotational axes is provided for the DUT. It has been decided to use a commercial unit for the actuator. This actuator has been ordered and has already been commissioned. A picture of it is seen in Fig. 8 The sensor boxes are designed in such a way that at least one reference plane can be moved to within a distance of 5 mm of the DUT. With such a setup the impact point of a beam particle on the DUT plane can be predicted with a precision of $\approx 1\ \mu$m even for the relatively low energy electron beam available at DESY.

3.3 C: Pixel Telescope

This task comprises the design and production of the telescope reference plane sensors. Sensors that are currently available will either be fast or precise but not both. In order to reach the design specifications with respect to precision, readout speed and active area a new pixel sensor needs to be developed. This chip will be a fully digital device which integrates both analog and digital circuitry on the sensor itself. The development of this sensor is part of the project scope and the availability of the first prototype for that sensor is the first milestone within JRA1 (JRA1-1). However, existing sensors can already be used to build a demonstrator telescope which will be a very useful facility available early on during the project's lifetime. The demonstrator will compromise on readout speed but will reach a precision very close to the design values at an early stage of the project. It will be available as a user facility during the middle of 2007. This allows to accelerate the evolution of the project, based on existing material and improves the synergy between the collaborating groups.

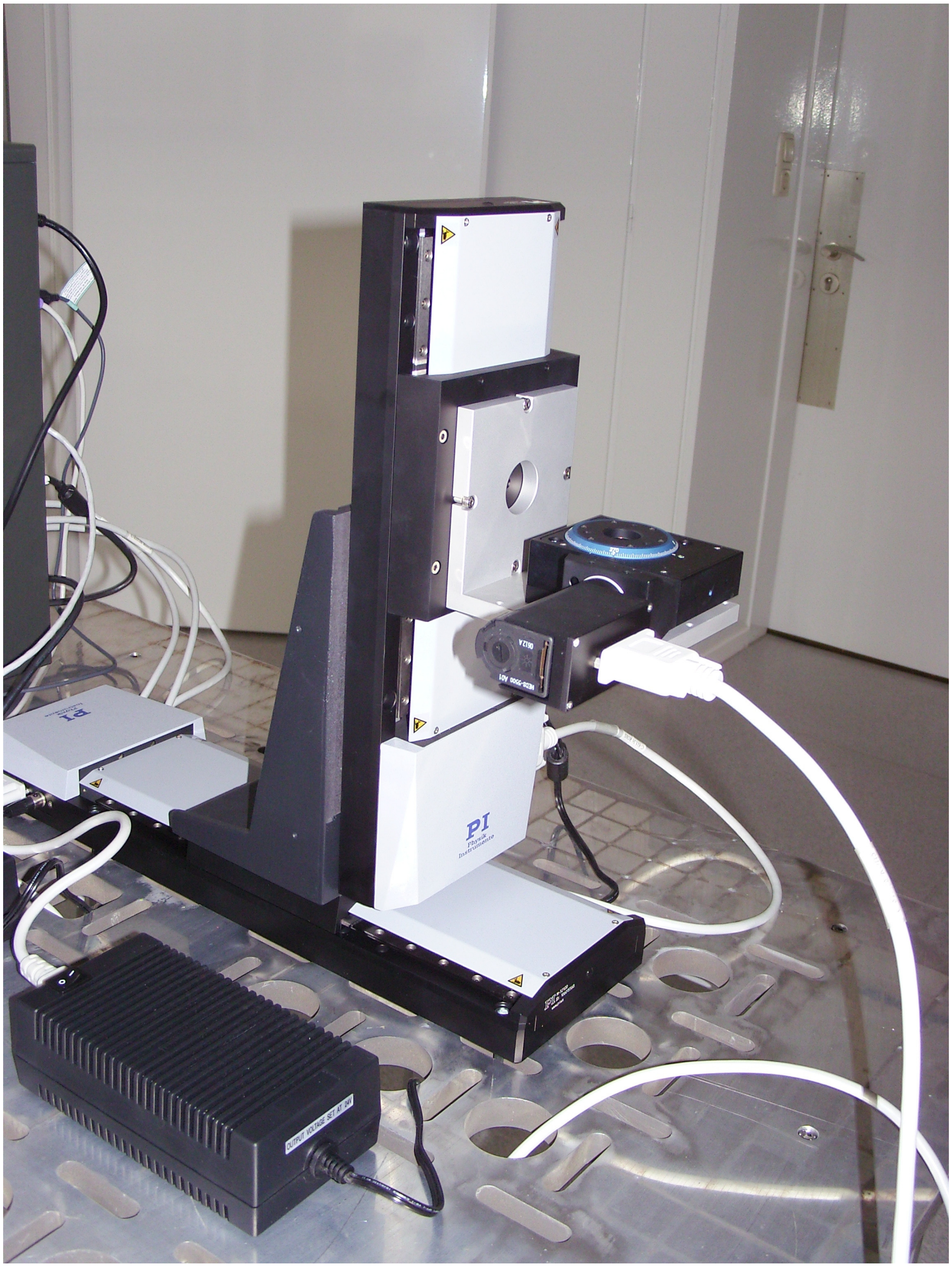

Figure 8: Picture of the DUT positioner.

3.3.1 Demonstrator Telescope

A monolithic active pixel sensor derived from a sensor originally developed for the STAR experiment at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven, NY, USA has been chosen as the sensor for the demonstrator. A small prototype of this chip called MIMO*2 was delivered to the partners early in 2006 together with the necessary read out infrastructure. This chip has 2 matrices of 128x64 pixels and a read out pitch of 30 μm. This prototype only differs from the demonstrator chip with respect to its size. The demonstrator chip itself is roughly 7×7 mm^2 and has 256x256 pixels with a pitch of 30 μm. It is done in an AMS 0.35 OPTO process. The chips were delivered from the foundry in October and are currently being prepared for mounting and bonding. Fig. 9 shows a MIMO*2 chip mounted on its proximity board.

Figure 9: MIMO*2 chip mounted on the proximity board.

3.3.2 Final Telescope

The final telescope sensors will provide a major improvement with respect to the demonstrator sensors in three respects:

- The readout speed will increase by one order of magnitude reducing the frame readout time from 1.6 ms to 100 μs;
- The sensitive area will increase by a factor 3.5 from 7.68×7.68 mm^2 to 20.48×10.24 mm^2;
- Several other improvements resulting from the ongoing R&D process will be integrated, such as signal amplification and data compression.

These goals will be achieved with a telescope chip which will be a fully digital device with digitization and sparsification circuitry integrated into the monolithic active pixel sensor. The first prototype device is the MIMOSA16 chip which came back from the foundry in October 2006. This completes milestone JRA1-1. Fig. 10 shows the layout of this chip. It contains a number of important ingredients that are needed for the final

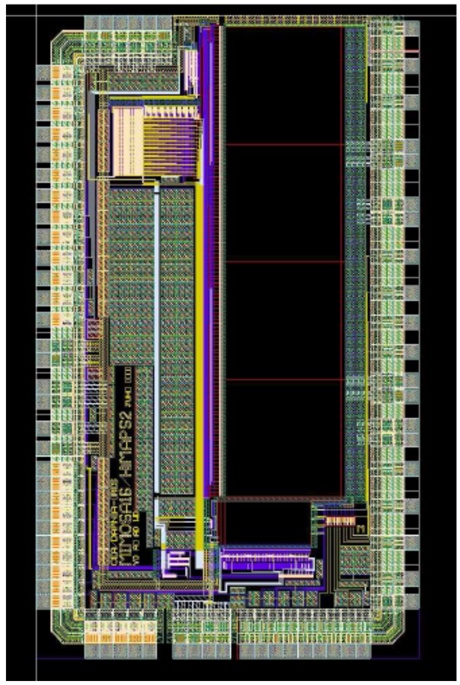

Figure 10: Layout of the MIMOSA16 chip.

telescope chip. These are:

- Column-parallel read out, namely 32 columns of 128 pixels each with a pitch of 25 μm;
- On-pixel correlated double sampling which is repeated at the end of each column;
- A discriminator at the end of each column.

The chips are currently undergoing extensive characterisation and testing in the lab. Beam tests are planned for summer 2007. In parallel the next generation prototype (SDC2) is being developed. This development currently focusses on replacing the discriminator by an ADC. This is required in order to reach the design precision. Four different ADC designs are being investigated by different partners. The final ADC design is expected in 2007. Development on the sparsification circuitry is currently starting and a first prototype is expected during summer 2007. Also parameter optimization is going on for the next generation prototype. This will be a large prototype with 320 columns of 256 pixels each and a pitch of 16 μm.

3.4 D: Data Acquisition and Evaluation Software

To profit from the test beam infrastructure designed within JRA1, a competitive data acquisition system (DAQ) needs to be designed. The DAQ will need to read out and combine data not only from the different planes of the pixel telescope, but eventually also from the device under test (DUT), which will be most of the time another pixel-sensor like device. Also the DAQ needs to handle external information of the test environment, for example run/beam related data. In addition, users of the test beam infrastructure should be able to integrate their DUTs into the existing framework in a simple and easy way, either at the hardware level, or at the software level. Because the demands to the DAQ are relatively light-weight compared to other experiments, the design of the acquisition system can be held relatively simple. Still, the design needs to be able to scale at a later stage of the development. Within JRA1, the University of Geneva is coordinating the DAQ efforts, combining hardware from INFN Milano/Ferrara, IN2P3 Strasbourg and University of Bristol together with software input from Universitt Bonn/Universitt Mannheim and IN2P3 Strasbourg. In the following, we will present a general overview of the upcoming DAQ, as well as detailed information about the ongoing hardware and software developments.

3.4.1 DAQ Overview

To integrate a device under test into the data acquisition of the JRA1 beam telescope, different methods have been evaluated:

1. Integration at hardware level: This needs a special purpose hardware interface which should be able to read out the telescope sensors and the DUT as well. While the final read out board for the telescope implements this possibility, we can probably use this approach only for very dedicated DUTs.

2. Integration at software level: The DUTs will provide their own DAQ hardware, but the data will then be treated by a common DAQ software. This approach puts most of the development effort on the side of the JRA1 working group and thus can also not be applied all the time. Still we foresee to use this approach eventually at the demonstrator level for dedicated DUTs.

3. Integration at data level: Both the beam telescope and the DUT use their own dedicated readout hardware and software, and the separate data streams are combined by inter-process communication of the different DAQ systems. This solution is problematic since it is difficult to properly synchronize events and configure the different devices during the startup phase.

4. Integration at trigger level (Fig. 11): This will be the default scenario for most of the applications. Completely different hardware and software can be used for the beam telescope and the DUT. The synchronization of the events will be performed using simple Trigger, Busy and Reset signals and the events will be combined offline. Run control and configuration can be well controlled using the "Busy" signal.

As an additional safety measure to avoid slippage of event numbers between DUT and beam telescope, the trigger unit can provide a dedicated event number which is read out by the DUT, thus guaranteeing a match between an event from the telescope and the DUT.

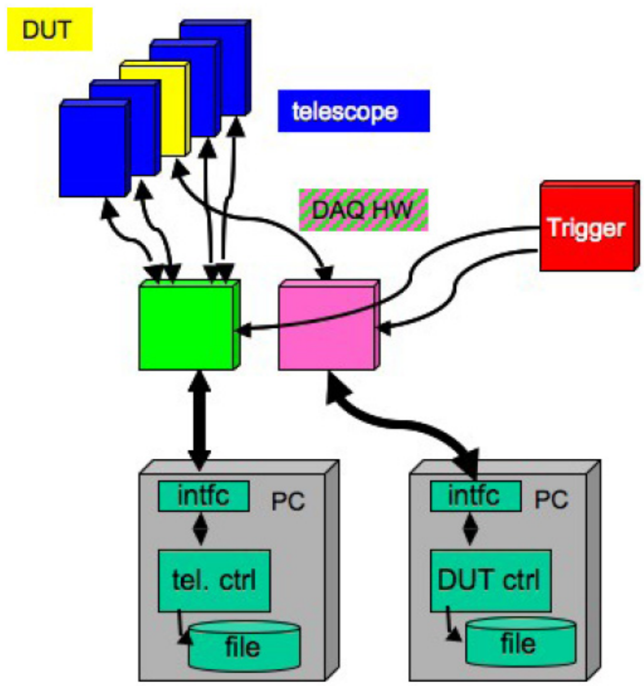

Figure 11: Integration of the DUT into the DAQ at trigger level.

The following sections looks in more detail at the necessary hardware and software for the realization of the above scheme.

3.4.2 DAQ hardware development

Dedicated hardware for the data acquisition of the beam telescope is currently under development. For early tests, IN2P3 Strasbourg is providing their existing hardware for the readout of the MIMO*2 and MIMO*3 pixel detectors. Based on the experience of the Strasbourg group, INFN Milano/Ferrara is currently developing a poweful generic readout system which is described in the following. We will also describe the Trigger Logic Unit (TLU), which has been developed by the University of Bristol to provide the integration of DUTs at the trigger level.

Eudet Data Reduction Board (EUDRB) of INFN Milano/Ferrara A picture of the EUDRB is shown in Fig 12. The key component of the board is an Altera FPGA which controls the analog and digital daughter cards, the input and output ports (trigger, RS232, USB 2.0 but mainly VME64x) and has access to memory for event storage. The

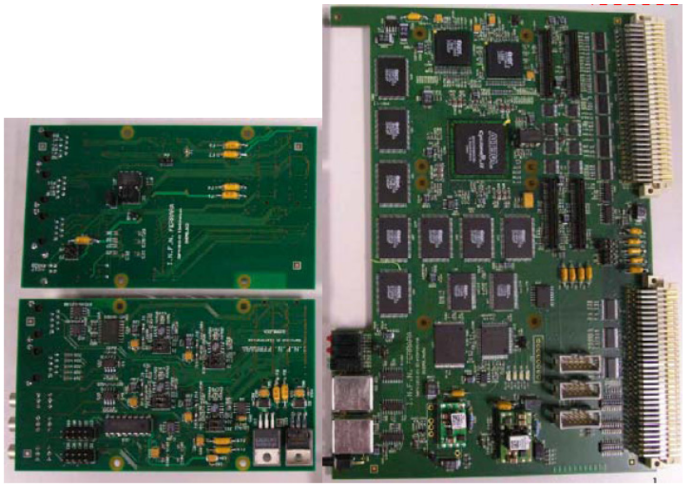

Figure 12: View of the EUDET Data reduction board (EUDRB). The motherboard is shown on the right and the digital daughtercard is shown on the left.

FPGA can be configured via a microcontroller unit (Altera Nios). The EUDRB will support two different readout modes: A zero-suppressed readout, thus minimizing the dead-time while in normal data taking and a non-zero suppressed readout of multiple frames. The second option can be applied also to hardware compatible DUTs. The board will be available for integration into the DAQ beginning of 2007.

Trigger Logic Unit (TLU) For simple integration of DUTs into the telescope, a trigger logic unit has been developed by the University of Bristol. The unit implements features like an event number and a timestamp of individual events. The design is based on a commercially available breadboard (ZestSC1) from Orange Tree Technologies. The TLU provides the following interfaces:

- A USB 2.0 connection for configuration and readout of the TLU timestamps and event numbers via a PC,
- Four Lemo input connections for the beam trigger (photomultiplier or similar). The input type can be configured via daughter cards, if needed,
- Six RJ45 connectors providing trigger, busy and reset signals,
- As an alternative two of the six interfaces can be configured as a TTL interface via Lemo connections.

In the easiest case of integration, the TLU provides a simple handshake. On request, the TLU provides a more sophisticated trigger data handshake. Pictures of the first unit (motherboard and assembled box) ar shown in Fig 13. Currently 2 units are in use in Bristol and Geneva. 3 more units are under production and will be distributed to other groups for test preparations.

Figure 13: Picture of the EUDET trigger logic unit TLU.

3.4.3 DAQ software development

The following strategy has been chosen in order to quickly arrive at results without blocking further developments: In a first step existing software packages from Universität Bonn/Universität Mannheim, IN2P3 Strasbourg and University of Bristol were combined as a proof of principle. In a second step this prototype software is being rewritten using most of the concepts in a generalized form.

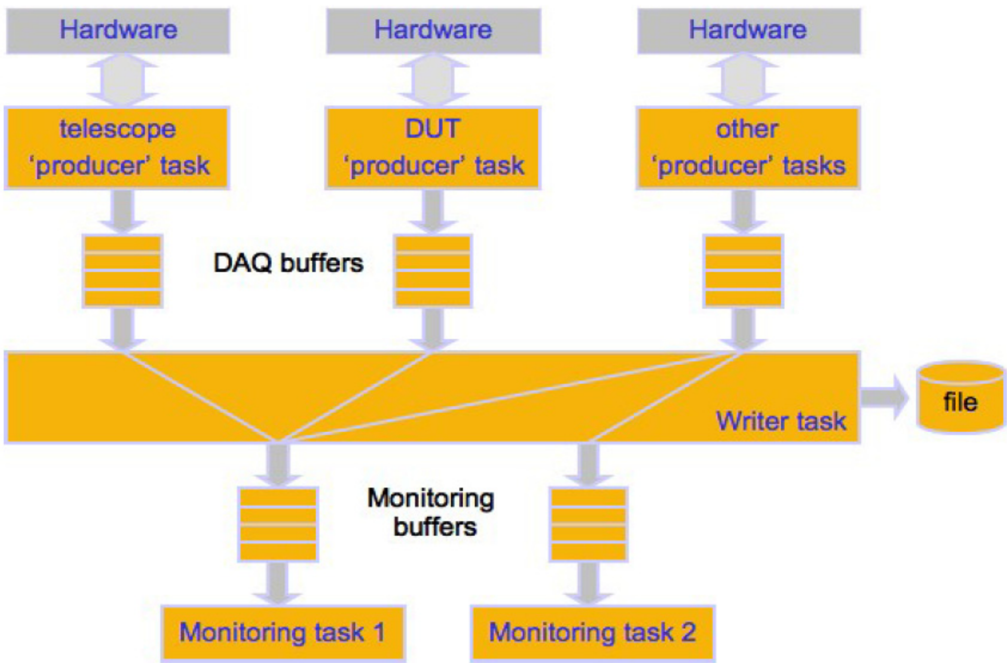

Figure 14: SW schematic based on the existing scheme from the DEPFET group.

JRA1 data acquisition software, version 1 In order to quickly come to a running DAQ, which is able to read out the JRA1 beam telescope as well as possible DUTs and the TLU, it has been decided to combine the existing DAQs into one. The skeleton from Fig. 14 has been used. The Strasbourg code and the TLU readout have been implemented in the form of independent producers. This system is currently up and running, but will be used only as a proof of principle. It lacks some essential functionality, like running on more than one computer, so a clean redesign, based on the above scheme, is currently under study.

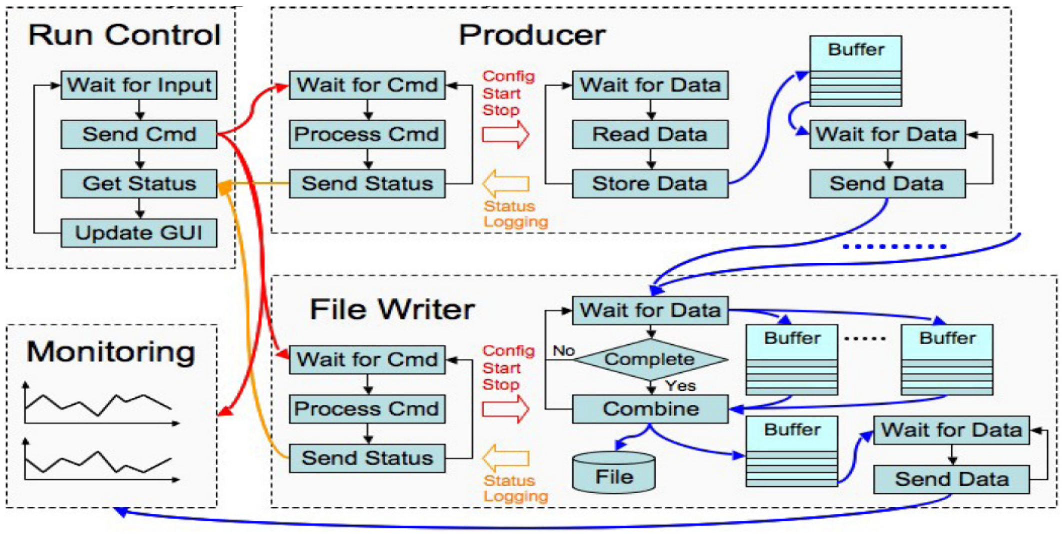

Figure 15: The scheme for the final JRA1 data acquisition.

Improvements for DAQ software, version 2 The DAQ software version 2 will be based on the scheme shown in Fig. 15. This scheme enhances the one shown in Fig. 14:

- A global Run Control takes care of all inter-process communication,
- The concept of shared buffers will be extended for data exchange across machines. Thus, producers and file writer processes do not need to run on the same machine and not even under the same operating systems. This will help users of the beam telescope to easily integrate their DAQ, if they wish to do so.

3.4.4 Next steps

The demonstrator telescope needs to be ready in July 2007, including a demonstrator DAQ system. To keep to the tight schedule, pre-integration of software and hardware will start in January 2007 at the University of Geneva, including a first EUDRB-card with a VME-readout, a TLU and first software versions. In early March, a frontend sensor will be added to the system and in April a second EUDRB will be added to the system. End of April, it is foreseen to ship the fully integrated DAQ system to DESY for global integration with the telescope hardware.
In parallel, the different DAQ working groups of EUDET are discussing to find common aspects in the design and try to harmonize their efforts. As a first success, we could convince the JRA3 group (responsible for the calorimeter) to use the TLU designed by

Bristol. JRA2 proposed some modifications of this unit, so that they could profit from the development as well. On the software side, a workshop in January 2007 will be used to investigate how common concepts could be implemented (e.g. the use of LCIO as data format and possible standardization of interprocess communications).

3.5 E: Validation of Infrastructure

In the original planning startup of this activity was foreseen during middle 2007 as the first version of the test beam facilities would become available. For this reason no specific results are reported here. However, the institutes involved in this activity have followed the planning from the very start and have actively participated in many decisions. In particular, it has been possible to profit from the extensive test beam experiences of these group. Specifically, the overall design of the DAQ software has been strongly influenced by these groups. In addition, the groups involved in the validation process have guided the mechanical design of the telescope.

References

[1] BESS Collaboration, Y. Ajima et al., ”A superconducting solenoidal spectrometer for a balloon borne experiment”, Nucl.Instrum.Meth.A443:71-100,2000.